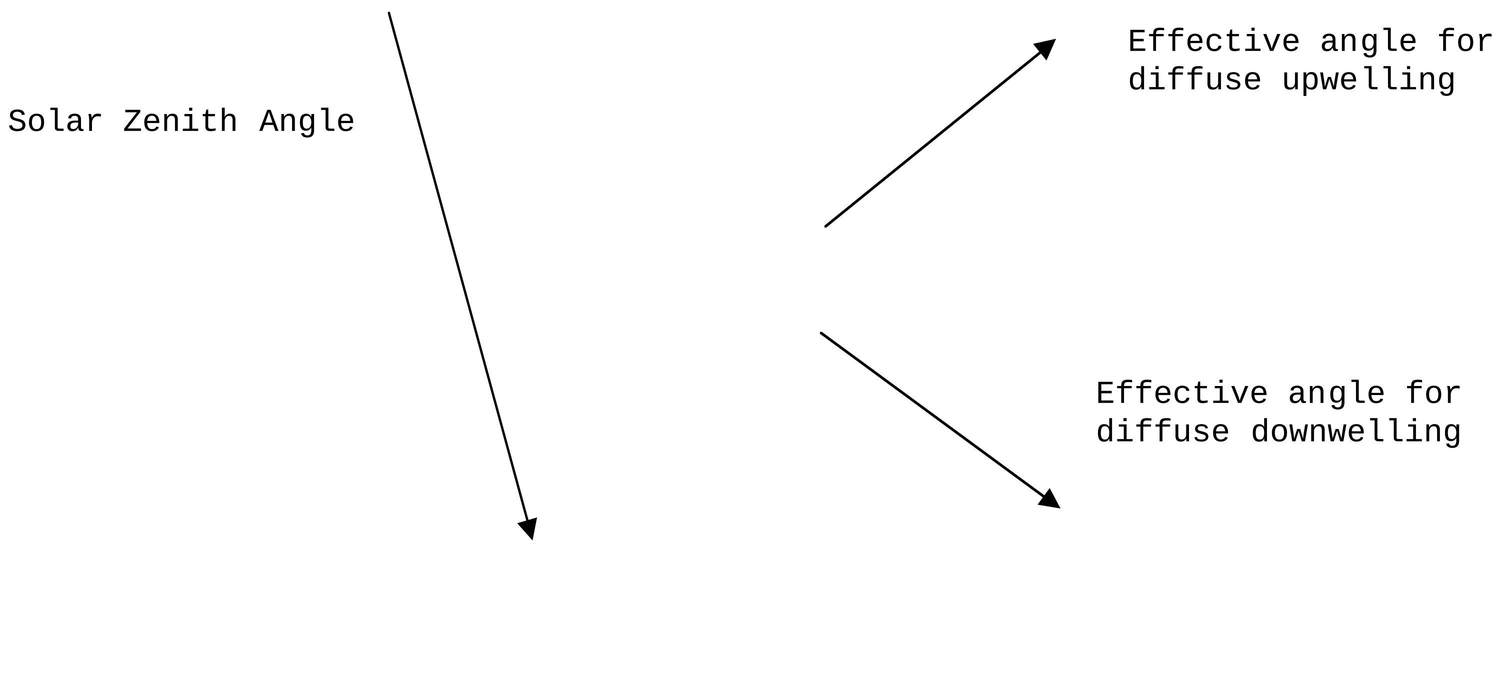
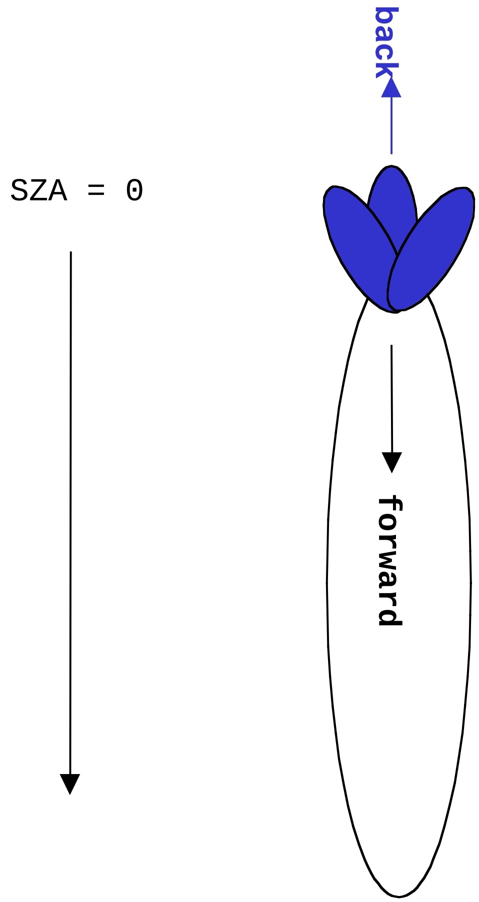
Low optical depth forcing and 2 stream SW radiative transfer

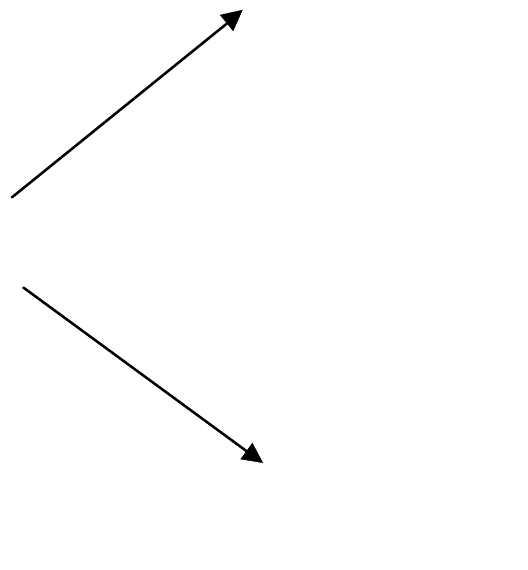
A cartoon essay on how the use of 2 stream for SW radiative transfer limits the SARB assessment of aerosol forcing at the level of ~10%. CERES CRS (SARB) uses 2 stream for pristine (aerosol free), clear sky (aerosols but not clouds), and full sky (everything - whatever clear or cloudy is found) SW calculations.

All radiation in 2 stream is at the SZA or at effective angle for diffuse.



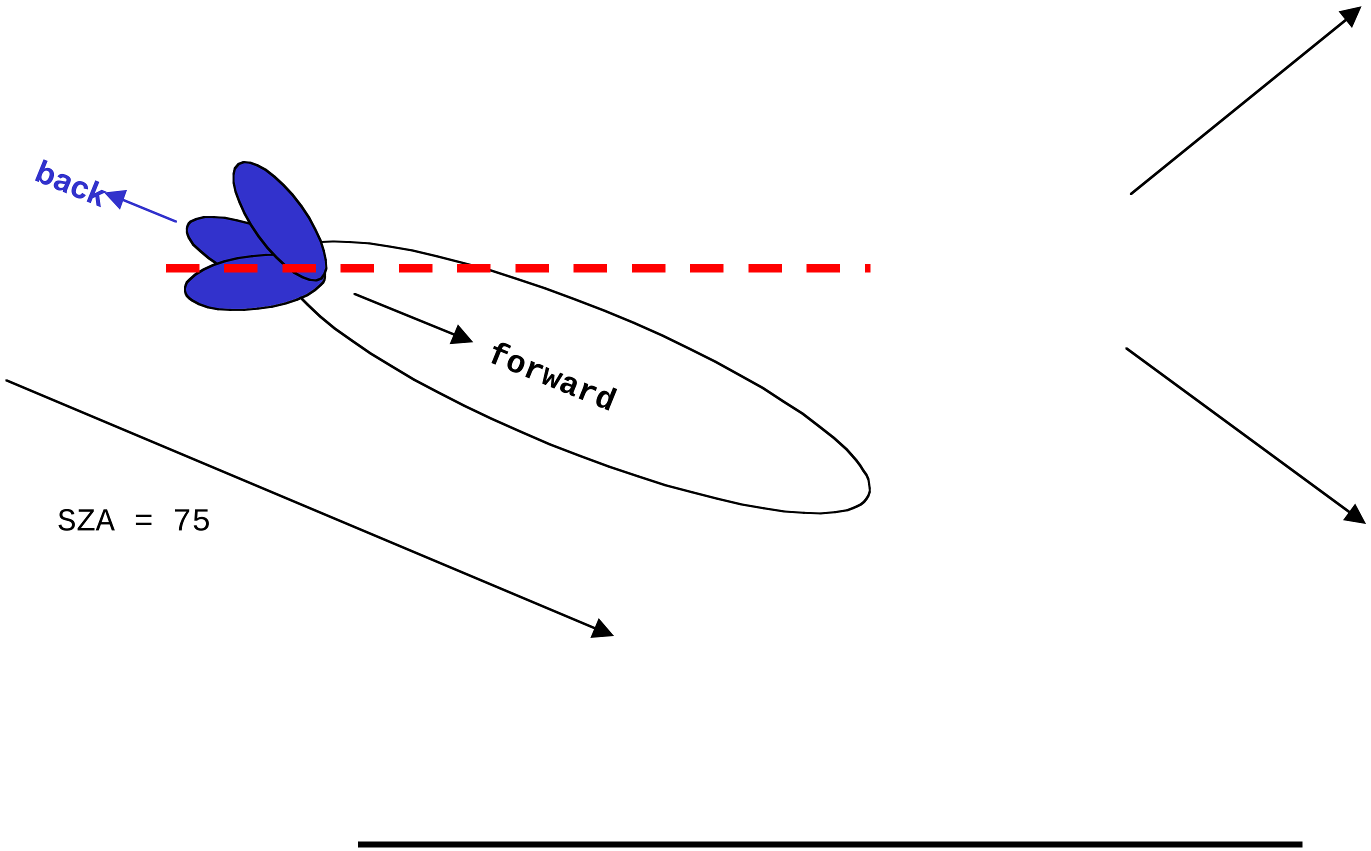
For overhead sun, the 2 stream treatment of the phase function with asymmetry factor g is pretty good. “Back” is assigned to the effective angle for diffuse upwelling. With the delta approximation, “forward” is apportioned into the direct and the effective diffuse downwelling beams.





Idealized scattering phase function

There is a problem at large SZA. The simple treatment of the phase function in most 2 stream schemes assigns the same fractions “back” and “forward”, as it did for overhead sun (SZA=0). We would really like a re-designed asymmetry factor, wherein the portion of the phase function above the red line is assigned to the effective angle for diffuse upwelling.



What is 2 stream doing to reflected SW at TOA (Wm-2)? While the abbreviated comparison with 4 stream below is hardly a full answer, it is consistent with physical intuition. The table gives 2 and 4 stream SW at TOA in Wm-2 for MLS assuming zero surface albedo. At large SZA (Uo=0.25), the forcings caused by low optical depth (tau = 0.2) clouds and aerosols are consisently underestimated (~10%) by 2 stream. This is probably due to the treatment of the phase function by 2 stream. Two stream sends the blue part of the phase function back to space – in the single diffuse upward stream. More properly, in a mostly-single scattering case, radiative transfer should send the portion above the red line back to space. In terms of TOA albedo, rather than Wm-2 as in the table, 2 stream is relatively better for overhead sun..

Reflected SW (Wm-2) at TOA for MLS, surface albedo = 0.

	Pristine		Forcing 60um ice cld at 11 km			
	tau=0.0		tau = 0.2		tau = 64.0	
streams	2	4	2	4	2	4
Uo=1.0	55.0	52.9	17.4	17.0	894.2	893.4
Uo=0.25	35.8	37.3	21.6	24.1	222.7	222.1

			Forcing 60um ice cld at 1 km			
			tau = 0.2		tau = 64.0	
streams			2	4	2	4
Uo=1.0			15.2	14.3	796.5	797.6
Uo=0.25			16.9	18.1	186.3	184.6

			Forcing of cont tau = 0.2			
			Scale ht. 10km		Scale ht. 1km	
streams			2	4	2	4
Uo=1.0			16.5	15.3	16.0	15.2
Uo=0.25			20.4	23.9	19.0	21.9

Q: Why the concern here? A: The accuracy of aerosol forcing in the CERES CRS (SARB) product. We archive pristine, clear sky, and full sky fluxes in CRS. For low optical depth cases, our 2 stream result should underestimate forcing by ~10% (i.e., difference of 21.6 and 24.1 in the bottom row of the first table).

Recognizing this small problem, one seeks a solution. Get the aerosol forcing (or forcing of small optical depth cirrus) by differencing our pristine calculation and the OBSERVED flux at TOA? But alas, the Pristine column in the first table shows that 2 stream is not perfect there, either.